Report of the Accelerator Systems Advisory Committee Of the Spallation Neutron Source September, 2002 Meeting

Introduction

The seventh meeting of the Accelerator Systems Advisory Committee (ASAC) for the Spallation Neutron Source was held on September 24 - 26, 2002 at the SNS Office in Oak Ridge, Tennessee. The committee membership is: M. Allen (SLAC), D. Boussard (CERN), A. Chao (SLAC), D. Finley (Fermilab), M. Harrison (BNL), R. Jameson (LANL), J.-L. Laclare (CEA, Saclay), W. McDowell (ANL), G. McMichael (ANL), D. Proch (DESY), G. Rees (RAL), P. Schmor (TRIUMF), and R. Siemann (SLAC, Chair). M. Allen, M. Harrison, J.-L. Laclare, and W. McDowell were unable to attend. H. Edwards (FNAL) and R. Kustom (ANL) joined the committee for this meeting.

Charge to Committee

I. Provide an assessment of the physics and technical progress on the project.
   - Does the committee see any serious problem areas?
   - As we have transitioned to installation (and soon commissioning) the focus is shifting to troubleshooting as issues arise – are we addressing these issues in an appropriate way?

II. Are there designs that could/should be improved within the constraints of funding and schedules? Are there any problem areas that might be potential show stoppers?

General Assessment

The overall impression from this meeting was very positive with substantial progress in many important areas. Highlights of these developments are:

- The Front End has been commissioned at LBNL. Specifications for beam current and emittance have been met, and there have been encouraging demonstrations of lifetime and reliability. The Front End was shipped to ORNL and installed in the SNS tunnel following the commissioning at Berkeley, and operation at the SNS is expected by the end of October. This is an outstanding accomplishment by the Front End team.
- A three-cavity cryomodule has been successfully tested at Jefferson Lab. RF input couplers were operated at high power, and the specified values of the gradient and quality factor (E_{acc} = 10 MV/m at $Q_0 = 5\times10^9$) were exceeded in all three cavities.
- Major parts of the refrigerator system have been delivered and are under installation in the central helium liquefier building. Impressive progress has been made on the assembly of the transfer line in the tunnel.
- There has been significant progress understanding and reducing the accumulator ring impedance. Impedances of some key components have been bench measured, and the impedance of the extraction kicker has been reduced by a factor of two. Because of this effort, the instability threshold is now estimated to be $2\text{x}10^{14}$, which corresponds to a 1.9 MW power level.
- Many of the high power RF components have been successfully tested, and delivery and installation have started. In particular, the problems with the 402.5 MHz klystrons have been resolved, and production of these tubes is proceeding well.
- Construction at the SNS site is impressive, and major technical components are being installed and made ready for commissioning.

The low level RF (LLRF), the Drift Tube Linac (DTL), and staffing for commissioning are particular issues that need attention. They are discussed next.

Low Level RF

The LLRF is a critical system, and it has fallen significantly behind schedule. The cryomodule test at Jefferson Lab provided an opportunity to test the LLRF, but the amplitude and phase loops could not be closed due to problems including unstable loop conditions and lack of a mechanism to understand and control set-points. As a consequence, flat top excitation of the cavity field could not be established. In addition, the temporary LLRF system that was developed for the front end commissioning at LBNL will have to be used for the re-commissioning of the Front End at ORNL.

Continuous testing of cryomodules is planned at Jefferson Lab during 2003. This is an excellent opportunity to test, modify and optimize the LLRF to produce a robust design for this complex control system.

The LLRF was reviewed at a one-day long meeting following the main ASAC meeting, and a separate report was written for that review.* It made organizational and technical recommendations and agreed with the importance of taking advantage of the opportunities for testing at Jefferson Lab.

The Drift Tube Linac

The DTL has encountered significant problems relating to the mechanical engineering of the end-wall, the drift-tube sealing, the welding of the drift-tubes, and damage to a significant fraction of the permanent magnet quadrupoles. Solutions have been evaluated and are being implemented.

However, the large number of mechanical problems leads us to recommend that an in-depth review of the DTL mechanical design should be conducted. This review should include:

1) The appropriateness of the solutions to the problems that have already been found,
2) Other potential mechanical problems that could arise,
3) The quality control plans for the remaining procurements and installation, etc,
4) The methods for drift-tube alignment, for realignment later if necessary, and for removal and replacement of a drift-tube,
5) The use of grease on O-ring seals. No grease causes high mechanical loading on the drift-tubes and may present considerable complications for the alignment and realignment procedures. However, the use of grease may cause breakdown in the DTL,
6) The long-term reliability and maintenance aspects of the end-wall and drift-tube designs.

Staffing for Commissioning

Commissioning of the SNS accelerator complex will be a time consuming activity that will make substantial demands on peoples' time and energy. The activities will range from *i)* turning on equipment and achieving beam to *ii)* reaching performance needed for CD-4 demonstration through *iii)* understanding of the accelerator performance at the design level.

The staff planned for the commissioning of the Front End and DTL does not appear to be adequate to perform this entire scope of work. There are only a small number of people; they are

* The review committee membership was D. Boussard, B. Chase (FNAL), H. Edwards, R. Jameson, R. Kustom, D. Proch, R. Siemann, C. Swanson (Alpha Cad), D. Teytelman (SLAC), M. Thout (LANL), and R. Urŝič (Instrumentation Technologies).

not going to be well supported by operations and maintenance staffs, and they are likely to have substantial additional responsibilities. As a result, unique opportunities to perform experiments that will provide essential information for rapidly reaching the ultimate performance of the SNS could be lost. The upcoming Front End re-commissioning provides an example. As a first step, the beam will have to be restored to the level achieved at LBNL. That will be followed by the unique opportunity to make measurements without the DTL in place, and effects of optics setting, hysteresis, etc on the emittance, Twiss parameters, and halo can be studied.

Ways to mitigate this problem include help from partner labs and consultants and additional commissioning time allocated in the Integrated Project Schedule. The next few months experience with the Front End commissioning should give guidance about the commissioning needs for the other, more complicated systems that follow.

The remainder of this report gives a broader discussion of the presentations and the committee responses and recommendations.

Front End

The Front End commissioning was an outstanding accomplishment. Major beam parameters met or exceeded the SNS commissioning requirements. This includes the current, transverse emittances, and lifetime and reliability during the running at LBNL. In particular, the RF antenna has been demonstrated to have good lifetime. There was good transmission through the RFQ, and beam profiles agreed with simulations. It was noteworthy that the commissioning activities at LBNL had important contributions of people and technical systems from the SNS partner laboratories.

There has been encouraging progress on a new, systematic, and practical treatment for removing bias and noise from raw emittance data. It has proven important for better measurements of the rms emittances, and, using this treatment, the emittances are substantially better than initially estimated. The effect of instrumental thresholds on the estimation of the beam halo is an important future direction. This new treatment will undoubtedly be adopted throughout the community.

The Front End was shipped to ORNL and installed in the SNS tunnel following the commissioning at LBNL. Operation at SNS is expected by the end of October, and Front End commissioning plans are well developed. We encourage the commissioning team to take advantage of a unique opportunity to understand the Front End beam before the first DTL tank is installed and diagnostics are no longer available. There are several reasons:

1) Reproducibility and stability will become increasingly important as the acceptance decreases. The better the understanding of the Front End adjustments and tuning, the easier the finding of a solution to match the beam into the tighter acceptance and for proper installation of the beam collimators.
2) Tests to date have looked at beam current, emittance, and transmission through the RFQ and MEBT. These values may change when the beam is matched into the acceptance of the downstream accelerators.
3) Good reproducibility of rms properties was reported from the LBNL commissioning, but it was noted that the halo properties are not as reproducible.
4) Beam chopping simulations that indicate that the resulting losses are within tolerance should be confirmed. Measurements should be made of the MEBT output parameters with temporary scrapers included in the anti-chopper straight section and with experimental simulation of partially chopped bunches by the use of a range of dc voltages on the LEBT and MEBT chopper plates.

5) The MEBT output beam parameters should be measured during the time when the beam is chopped to obtain the initial rise time to the full current level. These experimental results should be used both for final PARMILA simulations of downstream beam loss in the DTL and CCL and for MEBT target and scraper power estimates.

The opportunity to study the Front End is unique. We recommend that the "completion of commissioning" dates shown on the milestones be viewed as flexible and that, if necessary, that commissioning should continue as long as possible within other installation constraints, etc.

Diagnostics

The Front End commissioning at LBNL provided an opportunity to check out and verify five different prototype diagnostics systems – systems that are destined for the Front End, linac and accumulator ring. The success of the diagnostics and controls teams in commissioning these systems is an impressive accomplishment, and they are commended for taking advantage of the opportunity at LBNL. This experience shows the need for and importance of dedicated time for the diagnostics development, and such time should be included in future commissioning activities.

The tests indicated that the diagnostic packages are coming together nicely. The laser wire profile monitor was developed sufficiently that it could be included in the baseline with confidence that it will have good performance. Beam position monitor phase wander is of some concern that needs to be understood and corrected.

Controls

The Control system is in a good position, and the SNS Controls team was ready to support the Jefferson Lab Test Stand, is on schedule at the partner labs and with site installation. Commendable efforts include the Web-based CVS, viewer which gives the developers a graphical view of the software versioning status, and the Fast Interface developed for Diagnostics.

Modest changes to the controls hardware have provided the option for fast feedback via the control system. One possible use for this system would be control of the position and angle of the H- beam on the stripping foil, and an evaluation of such a system is recommended.

Room Temperature Linac

The main areas of concern are the low level RF and the mechanics of the Drift Tube Linac discussed above. Other aspects of the room temperature linac are making good progress. This includes the high power RF and the CCL production

A major issue discussed at the last ASAC meeting has been resolved with the successful delivery of the Marconi 402.5 MHz klystrons. Good results from the CPI 550 kW klystrons have been reported. This shows that a sound design exists and provides a comfortable safety margin. The Thales 550 kW klystron still exhibits stability problems, but this should not be considered critical at present time. The situation with the Thales 5 MW klystron is more serious. It suffers from overheating and efficiency limitations. New results are expected soon.

Tests of the SCR controller from Dynapower have been disappointing. Even though the problems have been fixed, they raise concerns about the robustness of the final design. This should be followed carefully.

The procurement and testing of other high power RF equipment proceeds smoothly, and the measures taken to mitigate the effects of late deliveries are in place. The progress of installation of linac RF equipment on the site is impressive, and the testing plan looks adequate although we have some concern about the manpower that will be available for this task.

CCL construction is underway at ACCEL. It appears to be proceeding satisfactorily with the first components now completed. The quality control plans for monitoring this procurement should be reviewed given the experience with the DTL.

ASAC suggestions and concerns from the last review have received appropriate consideration. Providing space for switches for electrical disconnect of the SRF klystrons is a good step. The cost of retrofitting should be carefully evaluated against installing the switches now, because they are likely to be needed to keep reliability high when SNS reaches design-operating levels.

Superconducting Linac

A successful test of a three-cavity, low-β cryomodule at Jefferson Lab was reported. The specified values for the gradient and quality factor (E_{acc} = 10 MV/m at Q_0 of $5x10^9$) were exceeded in all three cavities. A recently installed 1.3 MW klystron from LANL was used to operate the cavities and RF input couplers under high power conditions. The Lorentz force detuning was measured to be around 300 Hz at E_{acc} = 10 MV/m. This value could be reduced to 100 Hz by compensation using the piezoelectric tuners that were installed and tested. This detuning is considerably lower than the value of 460 Hz that was specified by acceptable klystron overhead power. The static cryogenic loss of the complete cryomodule was within specified value. No obvious microphonics were observed at Jefferson Lab, but, of course, conditions in the SNS accelerator tunnel will be different with respect to mechanical driving terms.

Additional investigations during the next acceptance tests of the cryomodules are advised: *i)* spread of mechanical resonances of cavities, *ii)* difference of coupling constant from piezoelectric tuner and Lorentz detuning to cavity frequency, and *iii)* origin of the observed 2 KHz modulation during Lorentz force detuning.

Unacceptable detuning of the field profile by a factor of three was experienced in one of the prototype module cavities. This is due to weakened mechanical properties of the Niobium after bake out at 800°C. Degassing of Hydrogen is needed to avoid enhanced RF losses by the "Q-disease"; this is especially true after electro-polishing. Earlier experience with chemically polished cavities made from prototype Niobium material indicated that a 600°C bake out was sufficient to remove the Hydrogen and did not affect the mechanical strength of the Niobium. However, it remains to be proven that this procedure is also successful after electro-polishing the new Niobium material from the production series. The apparatus for electro-polishing the high-β SNS cavities is near completion and will be commissioned soon. It is advised that metallurgical investigations of the production series Niobium be continued to understand the unusual mechanical properties of this material.

The amplitude and phase loop of the low level RF control (LLRF) could not be closed during the cryomodule test run. As consequence flat top excitation of the cavity field could not be established. This should be done with high priority at the forthcoming module tests. The cryomodule testing planned at Jefferson Lab during 2003 will provide excellent opportunities to accomplish this and to test, modify and optimize the LLRF system and approach a robust design for this complex control system

Accumulator Ring

Continued, good progress was reported on the ring magnet, vacuum, and RF systems. We look forward to the delivery by BNL of the first ring half-cell in November 2002 and to the results of the acceptance tests, which will be performed at ORNL.

Systematic magnetic measurements of ring and beam line magnets are underway. The ring dipoles have an rms variation of the integral transfer function at 1.0 GeV of 0.01% after shimming. The rms variation is 0.035% at 1.3 GeV. This is well within the capability of the corrections, and, if needed, sorting the dipoles can reduce the corrections. In addition, the field quality harmonics are acceptable.

Magnetic measurements of the integral transfer function have been attempted on eight quadrupoles destined for the ring or HEBT. However, the quadrupole magnetic measurement system has uncertainties of the same order as the desired accuracy of 0.01%. This needs to be resolved to qualify quadrupoles and assign them to the ring or HEBT. Nevertheless, one of the quadrupoles has been chosen for the first ring half-cell.

Other magnetic measurements have found and led to a solution of problems caused by the use of magnetic stainless steel coil clamps and water leaks traced to inadequate brazing methods. It is important to insure that these corrective measures are adequate for the long-term and that the solutions are applied to all magnets.

There is progress with the design of the magnetic field in the injection straight section. Field measurements are still needed to assure that the stripped electrons will indeed make it to the collection point. We support the addition of a window and video system to monitor the performance of the electron collection because it will help determine that the electrons are properly impinging on the carbon-carbon collector. It should be installed before beam enters the enclosure because it will be used during commissioning, and the injection area is expected to develop high residual radiation levels.

Over one-half of the ring vacuum components have been delivered. This is encouraging and gives good assurance that this subsystem is on track. But it is also recognized that the job won't be done until every element in the vacuum system is completely installed and operational.

The high power components of the SNS ring RF system make use of well-proven designs and show comfortable safety margins. Even though the power amplifier can fully compensate the beam current, its normal operating conditions will require much less power, thanks to the dynamic tuning that compensates the linearly rising reactive component of the beam current. The cavity demonstrated the required gap voltage capability and all high power RF components are now in the production stage.

The ring low level RF is somewhat unconventional because of the very short beam time, the very high beam loading, and the low Q of the cavities. Feedback loops ensure constant RF voltage in the presence of linearly rising beam loading. As customary in modern designs, the feedback loops are implemented digitally, with the advantages of flexibility and stability. The proposed algorithm seems well adapted to the particular case of the SNS ring RF and should provide complete correction of beam loading in the static case.

An important milestone (December 2002) will be the demonstration of the cavity IQ control loop performance. Transient response time, static response, overshoot, and response to a linearly rising beam loading should be measured. Beam loading can be simulated in these tests by modulating or ramping the RF frequency, as was done for testing the dynamic tuning. Fault management and interlock functions are essential parts of the LLRF system; they should be considered at an early stage of the design.

The non-RF longitudinal fields in the ring (longitudinal space charge and cavity and kickers wakefields) are not negligible, because of the very high beam current. They perturb significantly the evolution of longitudinal phase space, even though the instability thresholds are not reached. It would be useful to repeat the simulations of the evolution of longitudinal phase space in the presence of space charge, impedances, and for realistic initial distributions that are not necessarily smooth and uniform.

Substantial progress has been made on ring accelerator physics. We agree with the assessments that, at this point of time, the emphasis of accelerator physics is not so much for the design, but for quality assurance and for anticipating problems. In that sense, it is emphasized that the aim should not be limited to CD-4, but should go beyond that and anticipate problems all the way to the full design performance.

The study of collective effects should be continued even thought the reduction of the kicker impedance has reduced the urgency. Further reduction of impedances would be prudent in recognition that instability theories are typically dependable only to a factor of two. The impedance bench measurements and simulations should continue. Measurements of the RF cavity coupling impedances are recommended, and impedance QA should be integrated into the engineering design to avoid accidental introduction of unnecessary impedances.

TiN coating of vacuum chamber components has reduced the risk of electron-proton instabilities. The procedures for performing the coating and assuring it is adequate are nearing the maturity needed for production. Scrubbing has been taken into account using the up-to-date information from CERN, and the result is that a reasonable baseline design and mitigation schemes have been defined. However, the electron cloud instability is a difficult topic, and the study will have to continue. In addition, we encourage additional safeguards. We support the proposed installation of clearing electrodes; this installation requires access to the vacuum system. We also support the proposed addition of solenoid windings in the collimation area before there are elevated radiation levels there. In both cases decisions on when to procure and install the cables, power supplies, etc for a complete systems can be made based on experience, budget, and schedule.

Studies of beam halo development should continue. The aims should be *i)* obtaining estimates of the beam loss pattern around the ring, *ii)* how this is expected to change in the presence of machine errors when the ring collimator efficiency will be reduced, and *iii)* effective use of the adjustments and flexibility already included in the baseline design.

Simulations have been playing a determining role in many ring accelerator physics studies. A good effort has been made to develop a simulation program ORBIT. This effort should be continued with the aim of developing a code that is SNS-specific, and serving not only as a design code but also eventually a control code for the SNS operation/commissioning. The next effort will be to include various error effects into ORBIT, to be followed by adding a simulation engine for electron cloud effects. It is also strongly encouraged to benchmark the code against experiments and other simulation codes. This is especially needed when the code is applied to subtle effects such as halo generation.

Topics for the Next Meeting

We would like to hear presentations on the following at the next ASAC meeting.

1) The response to the recommendations of the low level RF review and progress on the low level RF system.
2) The RF reference system including the fundamental stability requirement, the principles being followed in the hardware realization for suitable stability, the hardware implementation planned, and the method for proving the stability in commissioning tests.
3) The implications of locking the accelerators to the neutron choppers. Work on neutron choppers is improving the tracking capabilities, but they may not be able to keep up with line-frequency changes. This would mean that the accelerator would not be locked to the AC line. There is a need to check operation when not synchronized

to the AC line to ensure operation and that losses will be acceptable. The chopper performance will not be known until late in the project and by then corrective action will be difficult. In addition, we would like to hear about the overall SNS timing system and the synchronization of the accumulator ring RF and extraction kickers to the neutron choppers.

Agenda Spallation Neutron Source ASAC Review
September 24-26, 2002

Tuesday, September 24

8:00	Closed Session		30
8:30	Welcome, Charge and Project Status	T. Mason	30
	SNS Accelerator Systems Overview	N. Holtkamp	45
	ORNL ASD Resources and Progress	D. Olsen	15
10:00	*Break*		*15*
10:15	Accelerator Physics Overview	S. Henderson	35
	Final Results of Front-End Beam Commissioning	R. Keller	25
	Diagnostics Commissioning at LBNL	T. Shea	25
	Front-End Installation	M. Hechler	15
11:55	*Lunch*		
12:55	Front-End Commissioning Plans	S. Alexandrov	25
	SNS Ion Source Progress	M. Stockli	25
	Controls and Safety System Status	D. Gurd	25
	Application Programming	J. Galambos	25
	Electrical Systems Installation	R. Cutler	15
2:50	Break and Site and RATS Tour		
5:00	Closed Session		
7:00	*Conference Dinner*		

Wednesday, September 25

8:00	Closed Session		30
8:30	Ring Overview and Progress	J. Wei	25
	Ring Magnet Measurement Status	P. Wanderer	25
	Linac, HEBT and RTBT Magnet measurement Status	T. Hunter	20
	Ring HP and LL RF System Progress	A. Zaltsman	25
10:05	*Break*		*15*
10:20	Vacuum System Progress, Coating and Surfaces	H. Hseuh	25
	Ring Collective Effects Overview	A. Fedotov	25
	Electron Cloud Effects Update	M. Blaskiewicz	20
	Instabilities and Feedback	S. Danilov	25
11:55	*Lunch*		*60*
12:55	Linac Overview and Progress LANL	D. Rej	25
	Linac Beam Chopping Studies	S. Nath	25

	DTL Manufacturing Status	K. Christensen	25
	SCL Laser Wire Profile Monitor	S. Assadi	25
	Final Design of Linac Diagnostics	M. Plum	25
3:00	*Break*		
3:15	DTL Testing and Commissioning Plan	E. Tanke	20
	Cold Linac Overview and Cryomodule Production	C. Rode	40
	Prototype Coupler and Cryomodule Voltage Testing	R. Campisi	25
	Cryo Plant Installation and Progress	D. Richied	20
5:00	*Closed Session*		

Thursday, September 26

8:00	Closed Session		30
8:30	High Power RF Progress	M. Lynch	25
	HP RF Testing Plan	R. Fuja	20
	RF Installation Progress	M. McCarthy	20
	LLRF Systems	TBD	60
10:35	*Break*	*15*	
10:50	Piezo Tuners and Lorentz Force Detuning	J. Delayen	25
	Preliminary Results of Integrated Cryomodule test	M. Champion	25
11:40	Closed Session and Lunch		120
1:40	Closeout		60
2:40	Departure and Start of LLRF Review		